Electronic
Second Stage

M.Sc. Zahraa Niema Kamal First Course Lecture Two

Lecture Two

Characteristic of Diode

1. Operation States of Diode

There are two important states for a PN junction, the reversed biased and forward biased states

1.1 Reversed Biased State

An electric field E is created in the depletion region because of the uncovered charges near the junction:

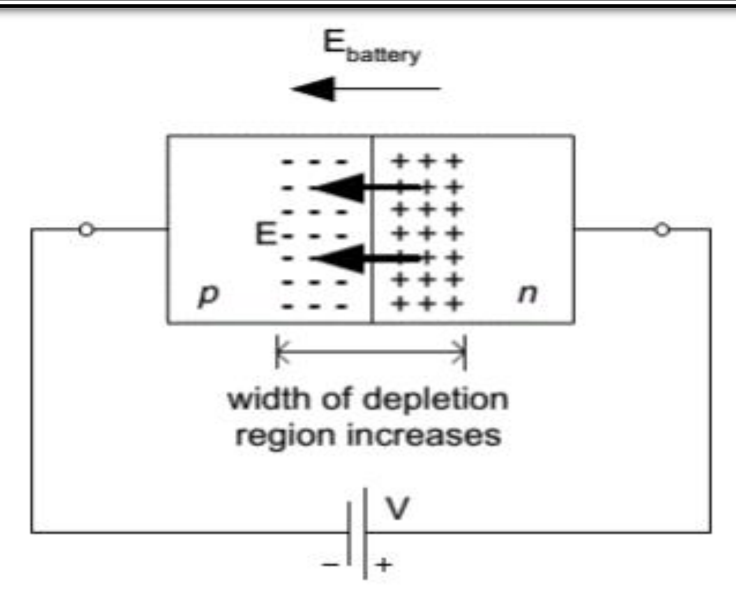


Fig. 7: Reverse biasing.

For the reversed biased state of the PN junction, the electric field produced by the battery **E** battery adds to this electric field of the space charge **E** in the depletion region. This increases the width of the depletion region. Consequently, the "majority carriers" cannot flow through the region: holes in the p material are opposed by **E** in the depletion region, as are electrons in the n material. Hence, little current flows (only the drift current I_S) unless the junction breaks

down. This occurs when **E battery** is strong enough to strip electrons from the covalent bonds of the atoms, which are then swept across the junction.

1.2 Forward Biased State

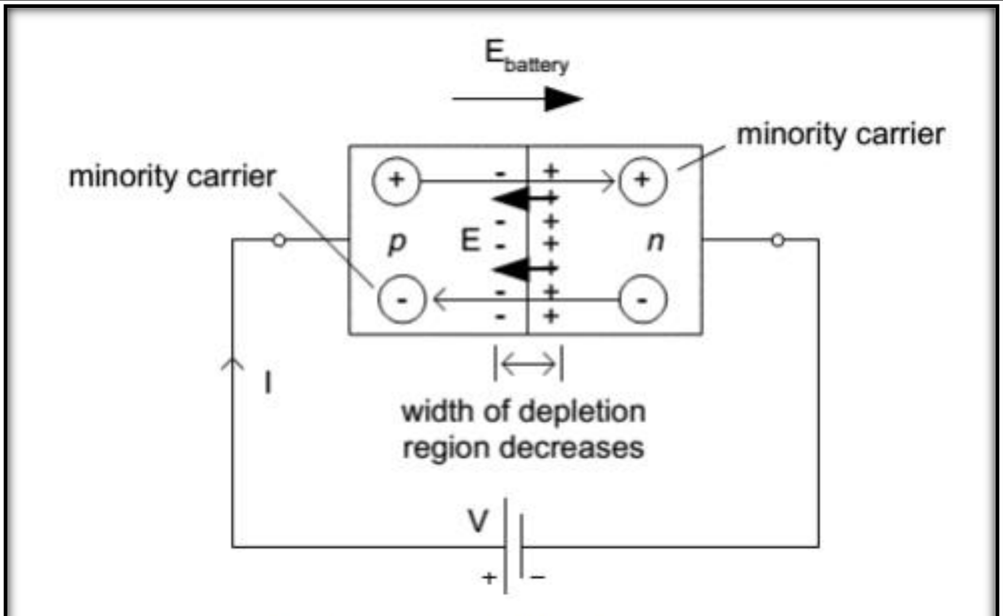


Fig. 8: Forward biasing.

When V is large enough so that **E battery** > **E**, Holes are swept from the p to n regions, and Electrons are swept from the **n** to **p** regions, then We now have current.

2. Current–Voltage Characteristic of the Diode

A semiconductor diode's behavior in a circuit is given by its current–voltage characteristic, or I–V graph (see graph below).

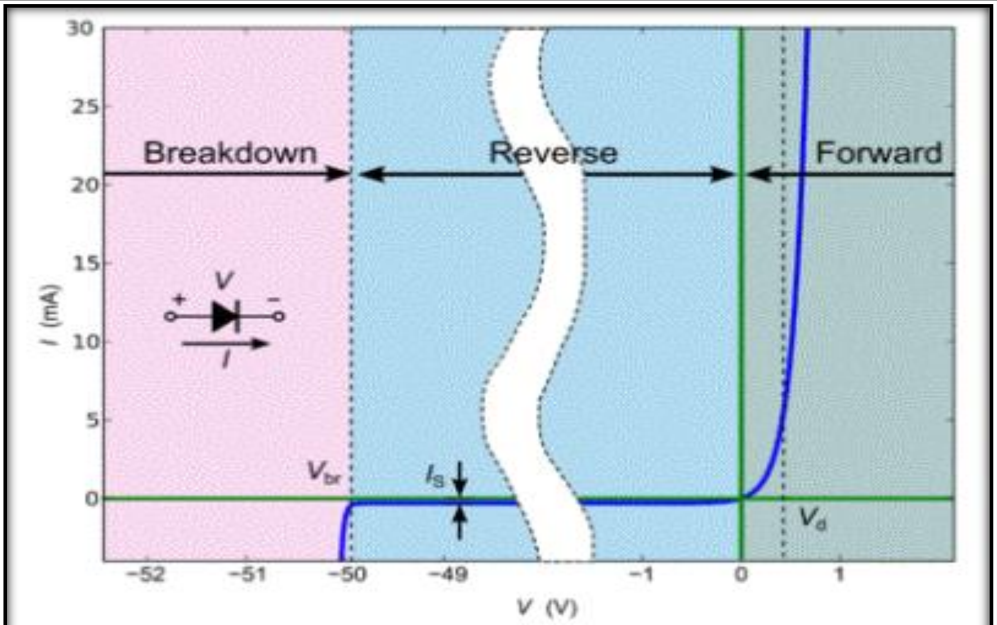


Fig. 9: I–V characteristic curve.

<u>A diode's I–V characteristic can be approximated by four regions of operation:</u>

1. At very large reverse bias, beyond the peak inverse voltage or PIV, a process called reverse breakdown occurs that causes a large increase in current (i.e., a large number of electrons and holes are created at and move away from the p– n junction) that usually damages the device permanently.

2. At reverse biases more positive than the PIV, has only a very small reverse saturation current. In the reverse bias region for a normal P–N rectifier diode, the current through the device is very low (in the µA range). However, this is

temperature dependent, and at sufficiently high temperatures, a substantial amount of reverse current can be observed (mA or more).

3. With a small forward bias, where only a small forward current is conducted, the current–voltage curve is exponential in accordance with the ideal diode equation. There is a definite forward voltage at which the diode starts to conduct significantly. This is called the knee voltage or cut-in voltage and is equal to the barrier potential of the p-n junction. This is a feature of the exponential curve and is seen more prominently on a current scale more compressed than in the diagram here.

4. At larger forward currents the current-voltage curve starts to be dominated by the ohmic resistance of the bulk semiconductor. The curve is no longer exponential; it is asymptotic to a straight line whose slope is the bulk resistance. This region is particularly important for power diodes. The effect can be modeled as an ideal diode in series with a fixed resistor.

In a small silicon diode at rated currents, the voltage drop is about 0.6 to 0.7 volts. The value is different for other diode types— Germanium diodes can be rated as low as 0.25 to 0.3 V, and red or blue light-emitting diodes (LEDs) can have values of 1.4 V and 4.0 V respectively. At higher currents the forward voltage-drop of the diode increases. A drop of 1 V to 1.5 V is typical at full rated current for power diodes.

3. Shockley Diode Equation

The Shockley ideal diode equation or the diode equation gives the I–V characteristic of an ideal diode in either forward or reverse bias (or no bias). The following equation is called the Shockley ideal diode equation when n, the ideality factor, is set equal to 1:

$$I = I_S\,(e^{VD/nVT} - 1)$$

Where I is the diode current, I_S is the reverse bias saturation current (or scale current), VD is the voltage across the diode, VT is the thermal voltage, and n is the ideality factor, also known as the quality factor or sometimes emission coefficient. The ideality factor n typically varies from 1 to 2, depending on the fabrication process and semiconductor material and in many cases are assumed to be approximately equal to 1 (thus the notation n is omitted).

The thermal voltage VT is approximately **25.85 mV** at **300 K**, a temperature close to "room temperature" commonly used in device simulation software.

At any temperature it is a known constant defined by:

$$VT = kT\ q$$

where **k** is the **Boltzmann constant 1.38 ×10^{-23} J/K**, **T** is the **absolute temperature** of the p–n junction, and **q** is the magnitude of charge of an electron **1.602 ×10^{-19} C**. The reverse saturation current, I_S, is not constant for a given device, but varies with temperature; usually more significantly than VT, so that VD typically decreases as T increases.

General Notes:

1. Under reverse bias voltages the exponential in the diode equation is negligible, and the current is a constant (negative) reverse current value of I_S.

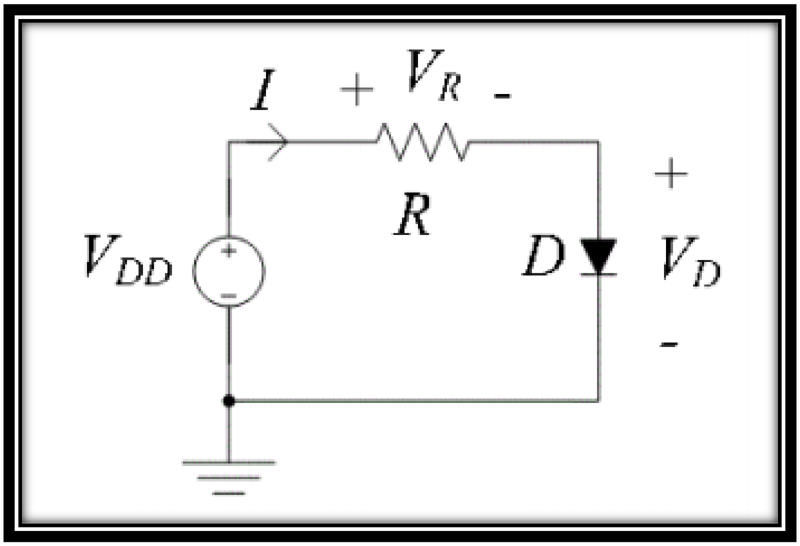
2. The reverse breakdown region is not modeled by the Shockley diode equation.

3. For even rather small forward bias voltages the exponential is very large, since the thermal voltage is very small in comparison. The subtracted '1' in the diode equation is then negligible and the forward diode current can be approximated by:

$$I = I_S e^{VD/(nVT)}$$

4. Circuit Analysis

Let's consider this very simple diode circuit:



We will assume that the diode is forward biased. Using KVL

$$VDD = I.R + VD \quad \text{.......} \quad (1)$$

From the characteristic equation for the diode

$$I = I_S [e^{VD/nVT} - 1] \quad \text{.......} \quad (2)$$

Assuming n, I_S, and VT are known, we have two equations for the two unknown quantities VD and I Substituting (2) into (1):

$$VD = VDD - R.I_S [e^{VD/nVT} - 1] \quad \text{.......} \quad (3)$$

Equation (3) is a nonlinear equation for VD. However, there is no simple analytical solution to this equation.

So how do we solve such a circuit problem? In this lecture we'll mention five methods.

1. ***Graphical Analysis.***
2. ***Simulation packages. SPICE, Agilent's Advanced Design System (ADS), etc.***
3. ***Numerical methods. Use Mathematica, MATLAB, Mathcad, etc.***
4. ***Iterative analysis.***
5. ***Approximate analysis. This is by far the most widely used approach for hand calculations.***

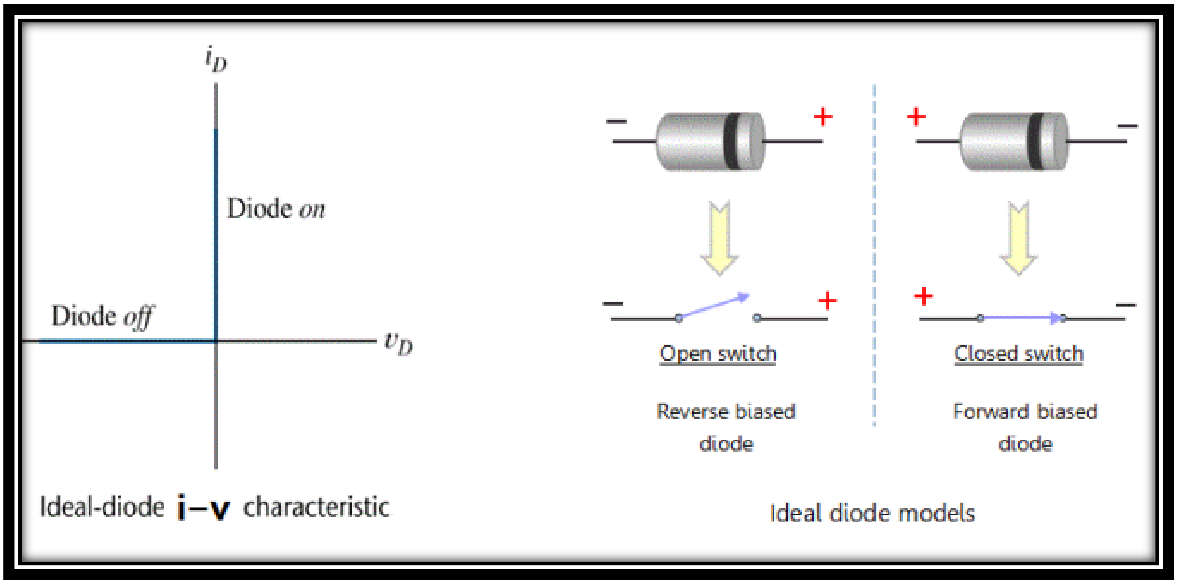
5. Approximate Diode Circuit Analysis

In this method we replaced the diode in the circuit by its approximate equivalent circuit. There are three very important approximate equivalent circuits for diode that allow easier hand calculations:

1. ***Ideal Model.***
2. ***Constant-Voltage-Drop (CVD) Model or Simple Model.***
3. ***Piecewise Linear (PWL) Model or Approximate Model.***

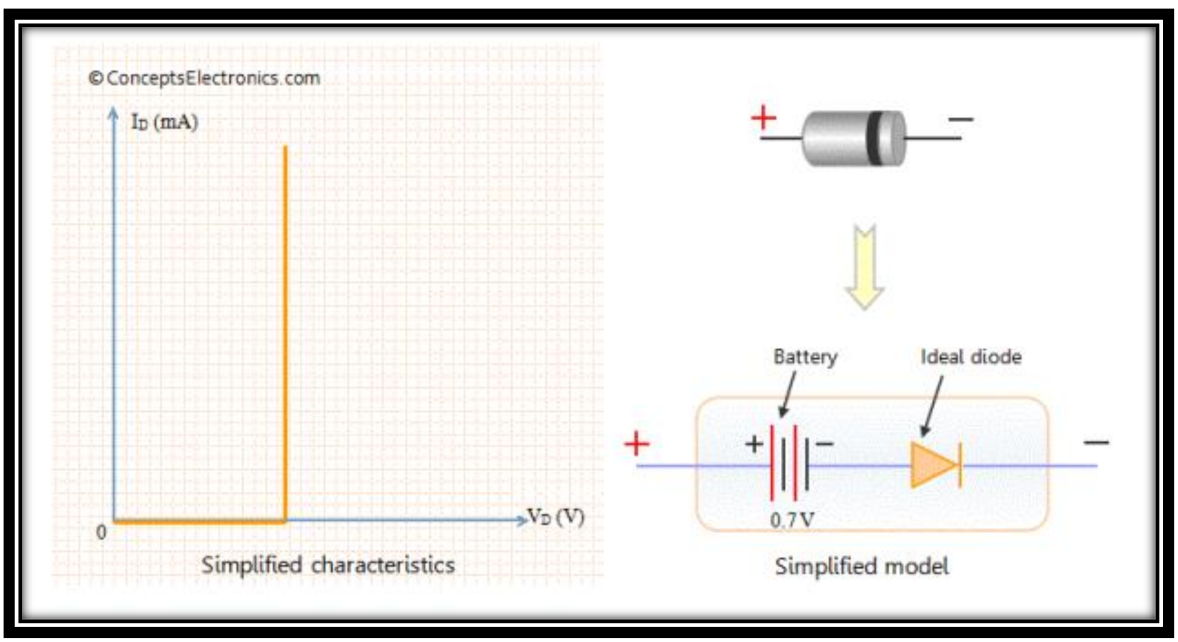
5.1 Ideal Model

In this model, the I-V characteristic curve of the diode is approximated as:



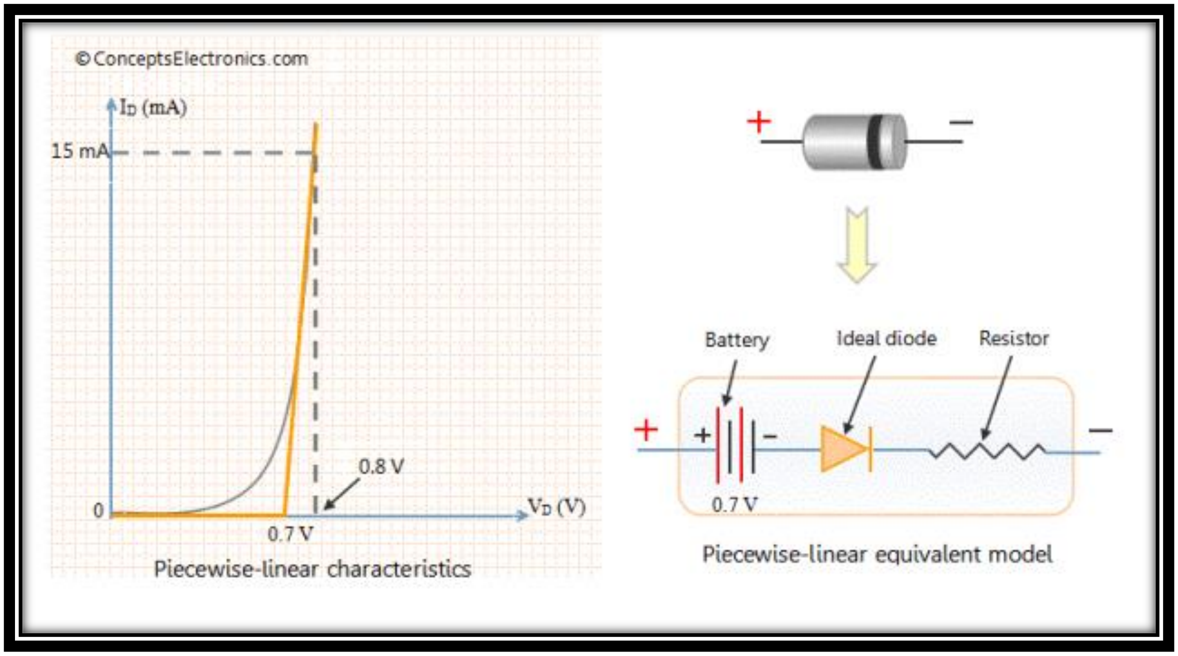
5.2 Constant-Voltage-Drop (CVD) Model or Simple Model

In this model, the I-V characteristic curve of the diode is approximated as:



1.5.3 Piecewise Linear (PWL) Model or Approximate Model

In this model, the I-V characteristic curve of the diode is approximated as:



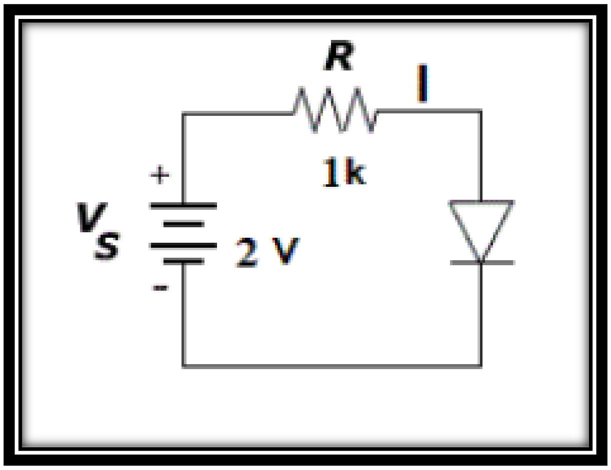
Example

Determine the current I in the circuit below using

(i) Ideal Model.

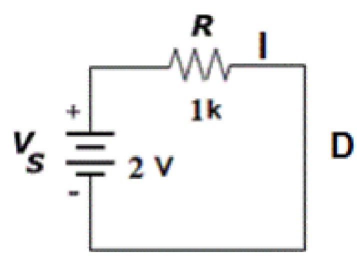
(ii) Simple Model.

(iii) Approximate Model, where rf = 5Ω.



Solution:

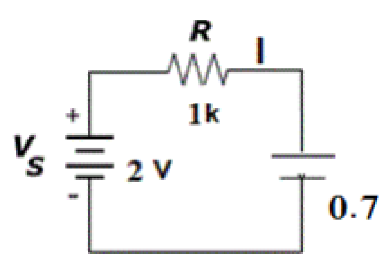
a) Assuming the diode in forward bias (On state), then redraw the circuit with replaced the diode by its equivalent circuit.



$$I = \frac{2}{1k} = 2mA$$

$\therefore I \geq 0 \;\rightarrow$ The assumption is correct.

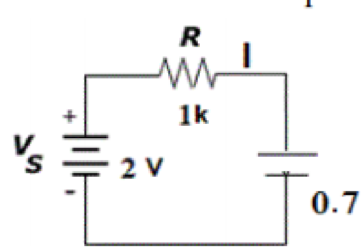
b) Assuming the diode in forward bias (On state), then redraw the circuit with replaced the diode by its equivalent circuit.



$$I = \frac{2-0.7}{1k} = 1.3 \text{ mA}$$

$\therefore I \geq 0 \;\rightarrow$ The assumption is correct.

c) Assuming the diode in forward bias (On state), then redraw the circuit with replaced the diode by its equivalent circuit.



$$I = \frac{2-0.7}{1000+5} = 1.2935 \text{ mA}$$

$\therefore I \geq 0 \;\rightarrow$ The assumption is correct.